iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 4 **Issue:** VIII **Month of publication:** August 2016

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Evaluation of Heat Flux by varying Tip Clearance Flow in Axial Compressor Rotor using Thermal Analysis

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Abstract: In this Paper analytical investigations are done to determine the effect of unsteady tip clearance flow in axial compressor rotor used in an industrial gas turbine. Thermal analysis is performed by changing the tip clearance 0.333 mm, 0.999 mm and 1.665 mm for different materials Monel K – 500 and Titanium alloy in air as fluid medium. 3D model of axial compressor rotor is drawn in Pro/Engineer and thermal analysis is done in Ansys to obtain total temperature and heat flux for Monel – k 500 and titanium alloy materials using air as a fluid. And Comparative analysis also has done by results of both materials to evaluation of heat flux by varying tip clearance flow in axial compressor rotor using thermal analysis.
Key words: Monel K – 500, Titanium alloy, total temperature, heat flux, thermal analysis

I. INTRODUCTION

Axial-flow compressors are used in medium to large thrust gas turbine and jet engines. The compressor rotates at very high speeds, adding energy to the airflow while at the same time compressing it into a smaller space. The design of axial flow compressors is a great challenge, both aerodynamically and mechanically. The aerodynamic compressor design process basically consists of mean line prediction calculation, through flow calculation, and blading procedures. The mean line prediction is the first step within compressor design. It is a simple one- dimensional calculation of flow parameters along the midheight line of the compressor where global parameters as the annulus geometry, the number of stages, and the stage pressure ratios are scaled.

Tip clearance is the distance between the tip of a rotating airfoil and a stationary part. Tip clearance in centrifugal compressor causes the leakage of high pressure fluid from pressure surface to suction surface of the impeller blade, making the flow field highly complex and affecting the performance.

Monel K500 is a precipitation-hardenable nickel-copper alloy that combines the excellent corrosion resistance characteristic of Monel 400 with the added advantage of greater strength and hardness. These amplified properties, strength and hardness, are obtained by adding aluminum and titanium to the nickel-copper base and by a thermal processing used to effect precipitation, typically called age hardening or aging. When in the age-hardened condition, Monel K-500 has a greater tendency toward stress-corrosion cracking in some environments than Monel 400. Alloy K-500 has approximately three times the yield strength and double the tensile strength when compared with alloy 400. Plus, it can be further strengthened by cold working prior to precipitation hardening. The strength of this nickel steel alloy is maintained to 1200° F but stays ductile and tough down to temperatures of 400° F. Its melting range is 2400-2460° F.

Titanium alloys are metals that contain a mixture of titanium and other chemical elements. Such alloys have very high tensile strength and toughness (even at extreme temperatures). They are light in weight, have extraordinary corrosion resistance and the ability to withstand extreme temperatures. However, the high cost of both raw materials and processing limit their use to military applications, aircraft, spacecraft, medical devices, highly stressed components such as connecting rods on expensive sports cars and some premium sports equipment and consumer electronics. Although "commercially pure" titanium has acceptable mechanical properties and has been used for orthopedic and dental implants, for most applications titanium is alloyed with small amounts of aluminium and vanadium, typically 6% and 4% respectively, by weight. This mixture has a solid solubility which varies dramatically with temperature, allowing it to undergo precipitation strengthening. This heat treatment process is carried out after the alloy has been worked into its final shape but before it is put to use, allowing much easier fabrication of a high-strength product

II. LITERATURE REVIEW

Venkateswara Babu, N Sitaram, M Govardhan [4], studied experimental investigation of tip clearance effects on flow field in an annular turbine cascade. The experiment take on inlet, in the blade passage, and exit of the cascade using five hole probe and seven hole probe. The author found that secondary and tip clearance losses steeply increase lower side of the blade trailing edge indicating additional losses due to vortex and clearance flow mixing with the main flow. And all this occurred finally losses in linear turbine cascade so the efficiency lowers down. Topology and vortex structures of turbine cascade with different tip clearance studied by Han Warrjin, Yang Qinghai, Huang Hongyan, and Jia Lin [5]. They found that the different-different clearances the blade to eliminate the upper passage vortex, waken the blade tip separation and thus reduces the relative leakage and energy loss. Topology and vortex structures of the cascade wall surface flow changes than vortex intensity, scale and its partnering effect, increases so loss of energy in flow. Unsteady loss in a high pressure turbine stage studied by S.J.Payne, R.W. Moss, and N.W.Harvey [6]. They measure four major loss mechanisms: the tip leakage vortex, the upper passage vortex, the wake and the lower passage vortex. They finally found that the tip leakage vortex have major entropy generation than other losses. Heat transfer of a gas turbine blade have effect of rim location, rim height and tip clearance on tip etc. studied by Jae Su Kwak, Jaeyong Ahn, Je-chin Han[7]. By using a rimmed tip blade, the heat transfer coefficients on the blade tip and shroud were reduced significantly. They observed that the rim height increased the heat transfer coefficient on the tip decreased. On the pressure side, the effects of the rim height, rim location, and tip gap clearance on the heat transfer coefficient were not significant.

III. THERMAL ANALYSIS

Thermal analysis of axial flow compressor rotor is performed in Ansys tool. Before that 3d model drawings were drawn in pro engineer design software. Fig 1 and fig 2 shows the imported model and meshed model in Ansys to perform thermal analysis.

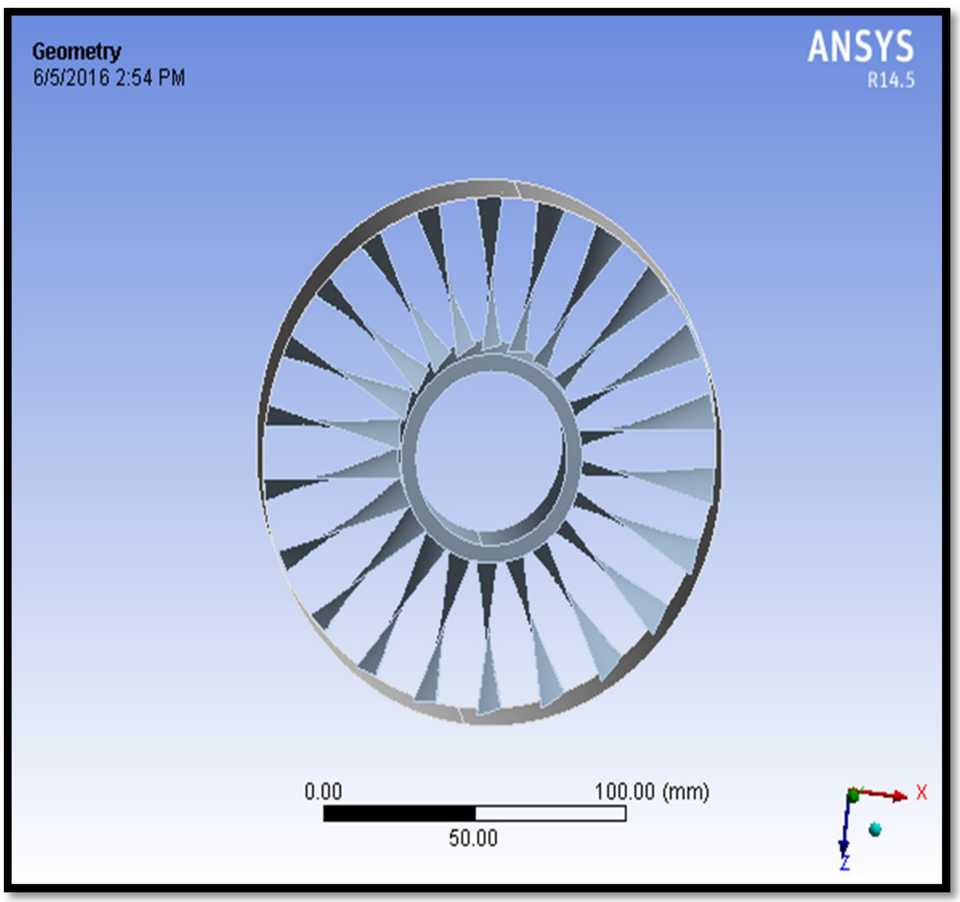

fig 1: imported model

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ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

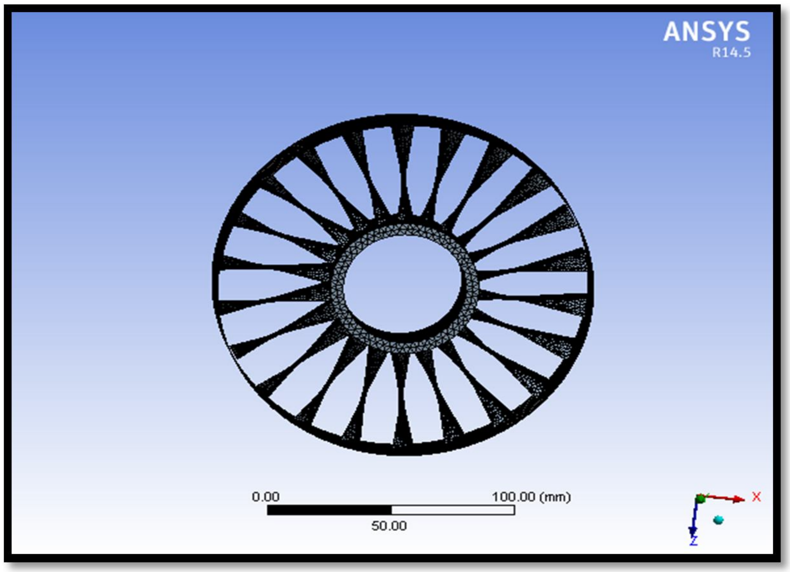
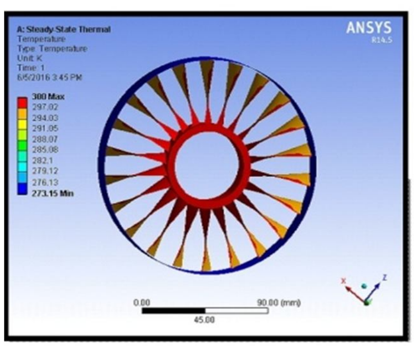


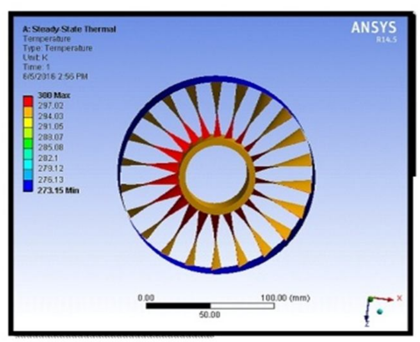
fig 2: meshed model

Thermal analysis by using Air as fluid medium .Here thermal analysis results are total temperature of Monel k 500 shown in fig 3 and titanium alloy total temperature shown in fig 4. And heat flux results of both materials can e shown in fig 5 and fig 6 at various tip clearances.

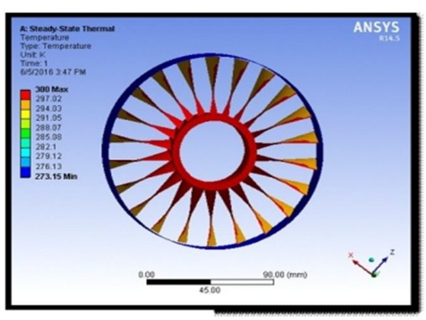
A. Total temperature of Monel K 500



0.333 mm



0.999 mm



1.665 mm

Fig 3: total temperature of monel – k material at various clearance tips

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ISSN: 2321-9653
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B. Total temperature of Titanium Alloy

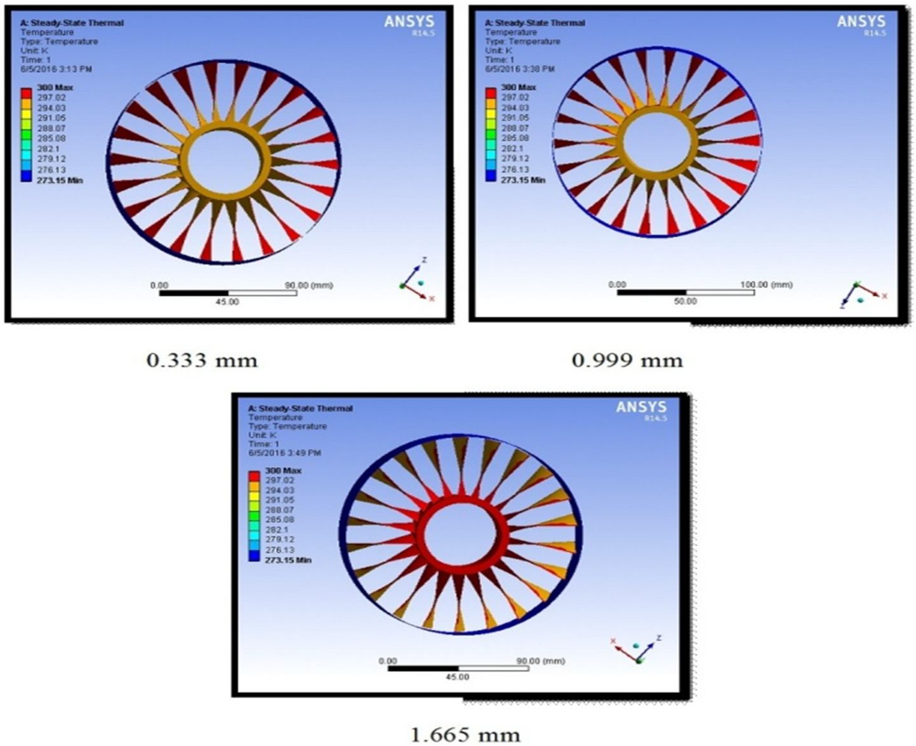

Fig 4: total temperature of Titanium alloy material at various clearance tips

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C. Heat Flux Of Monel K 500

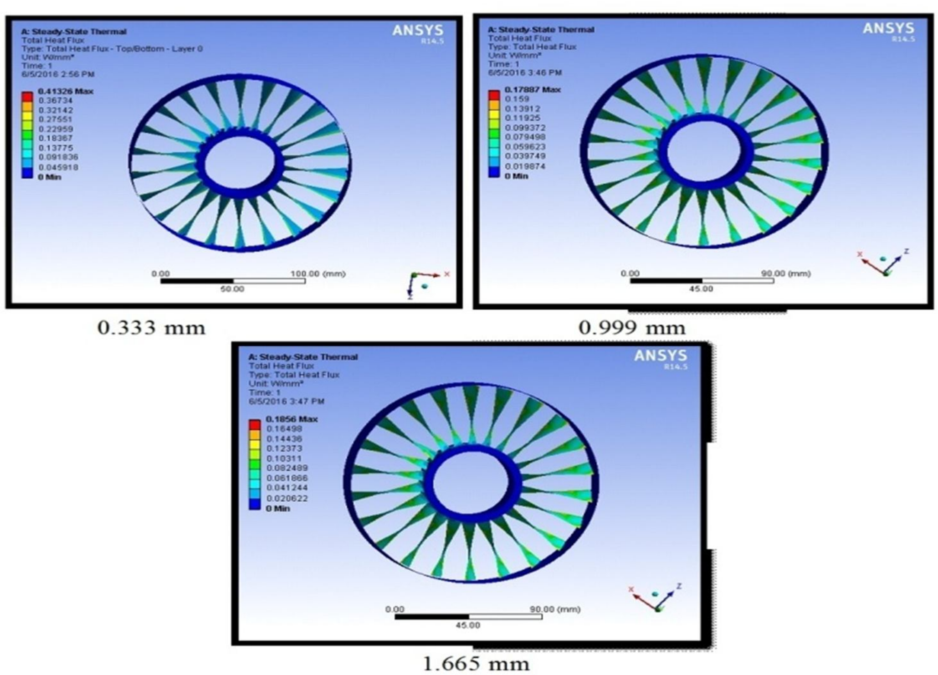

Fig 5: heat flux values of monel – k material at various clearance tips

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ISSN: 2321-9653
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D. Heat Flux of Titanium Alloy

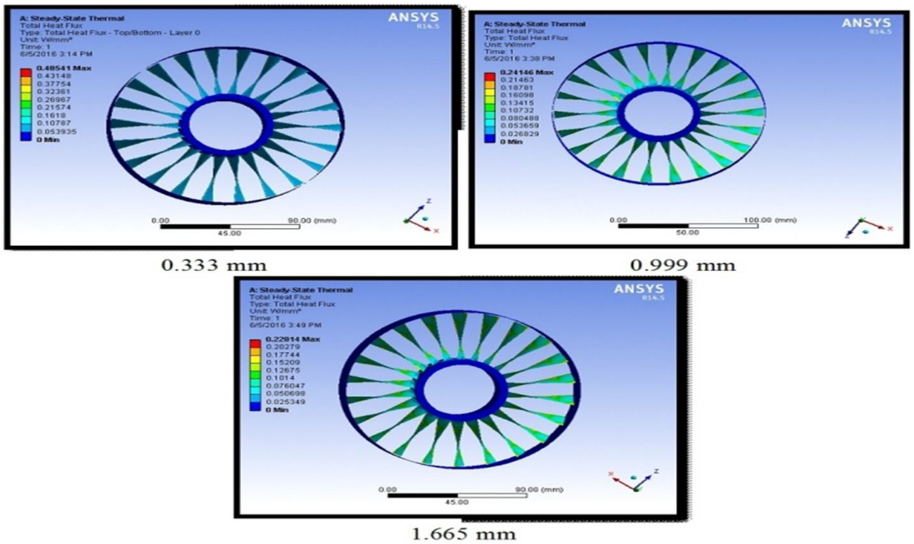

Fig 6: heat flux values of titanium alloy material at various clearance tips

IV. RESULTS AND DISCUSSIONS

We have done thermal analysis by using two different materials are Monel k 500 and titanium alloy in fluid medium air at tip clearances 0.333 mm, 0.999 mm and 1.665 mm. By the above results we extracted table 1. It is noticed that there is no change in temperature when we are varying tip clearance. And which can says that heat flux is decreased when we are increasing the tip clearance In both Monel k 500 and titanium alloy. The same way comparison of both materials in total temperature and heat flux values of graphical representation is given in fig 7 and fig 8.

TABLE 1 THERMAL ANALYSIS RESULTS

Fluid	Tip Clearance	Air	
Material		Total Temp	Heat Flux
Monel-K	0.333	300	0.41326
	0.999	300	0.17887
	1.665	300	0.1856
Titanium Alloy	0.333	300	0.48541
	0.999	300	0.24146
	1.665	300	0.22814

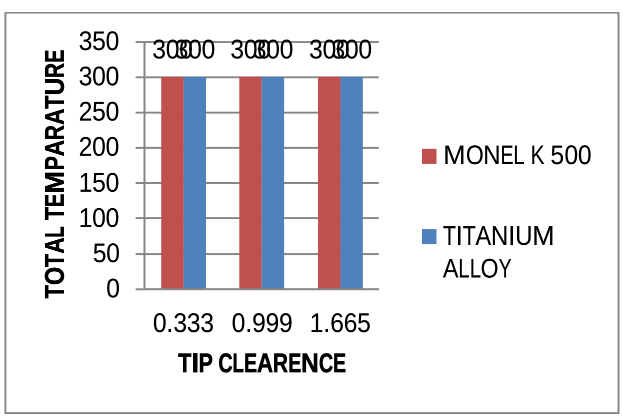

Fig 7: Comparison of total temperature for different materials at different clearance values for air as fluid

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ISSN: 2321-9653
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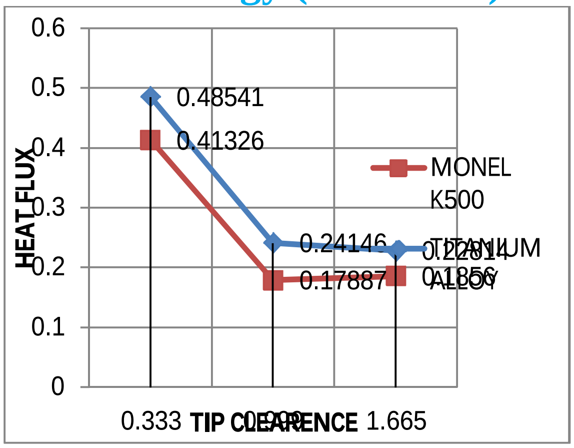

Fig 8: Comparison of heat flux values for different materials at different clearance values for air as fluid

V. CONCLUSIONS

In this thesis investigations are done to determine the effect of unsteady tip clearance flow in axial compressor rotor used in an industrial gas turbine. Thermal analysis is performed by changing the tip clearance 0.333mm, 0.999mm and 1.665mm for different materials Monel K – 500 and Titanium alloy. Analysis will also be done for Air. 3D modeling is done in Pro/Engineer and analysis is done in Ansys. By observing the thermal analysis results, heat flux values are increasing by increasing the clearance ratio. Heat flux values are more for Monel k500 than titanium alloy material in fluid Air. So it can be concluded that less clearance ratio, Air fluid and Monel k 500 is better.

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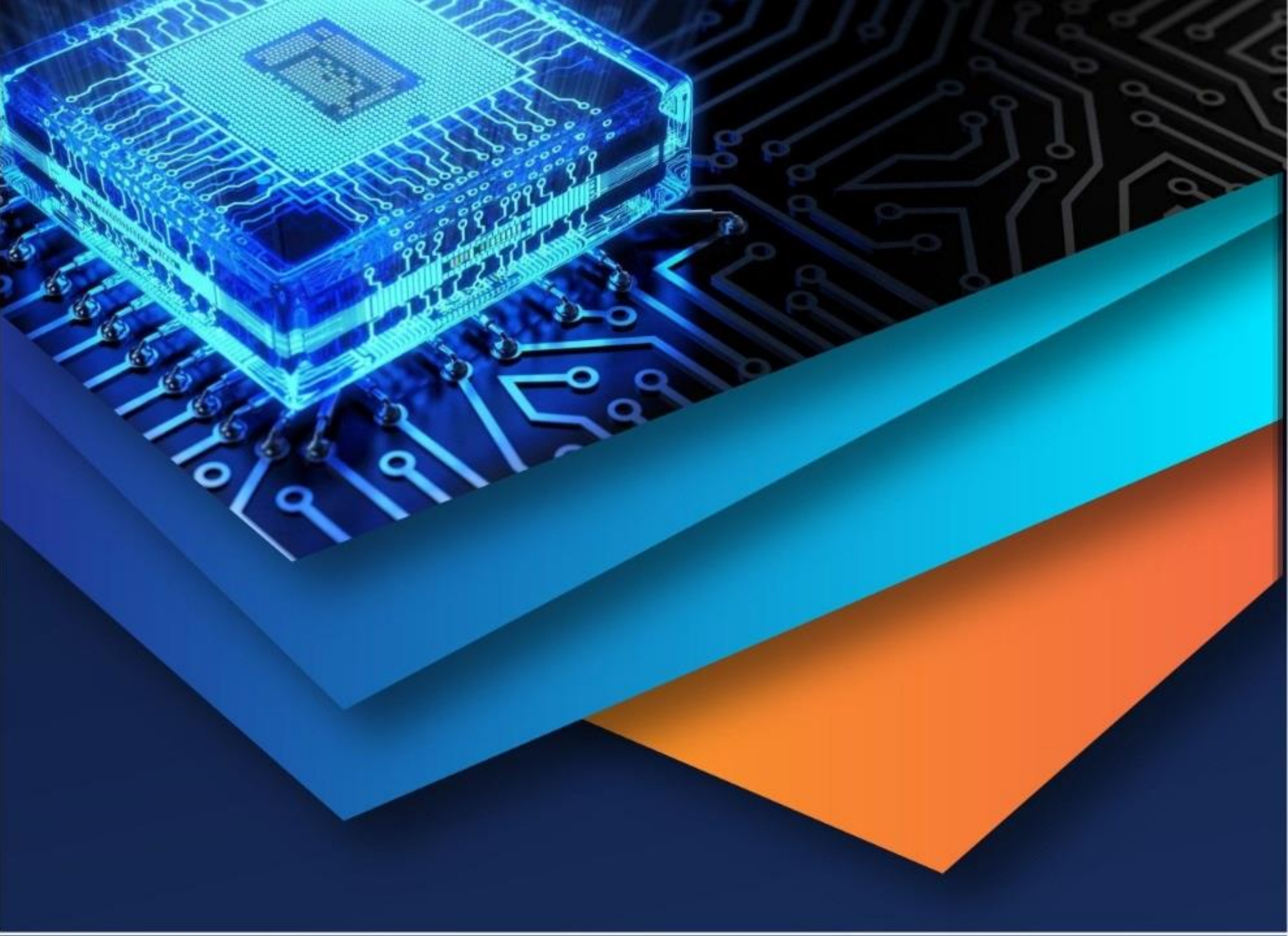

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